High Performance Wireless Local Area Networks in the 2.4GHz ISM Band

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Outline

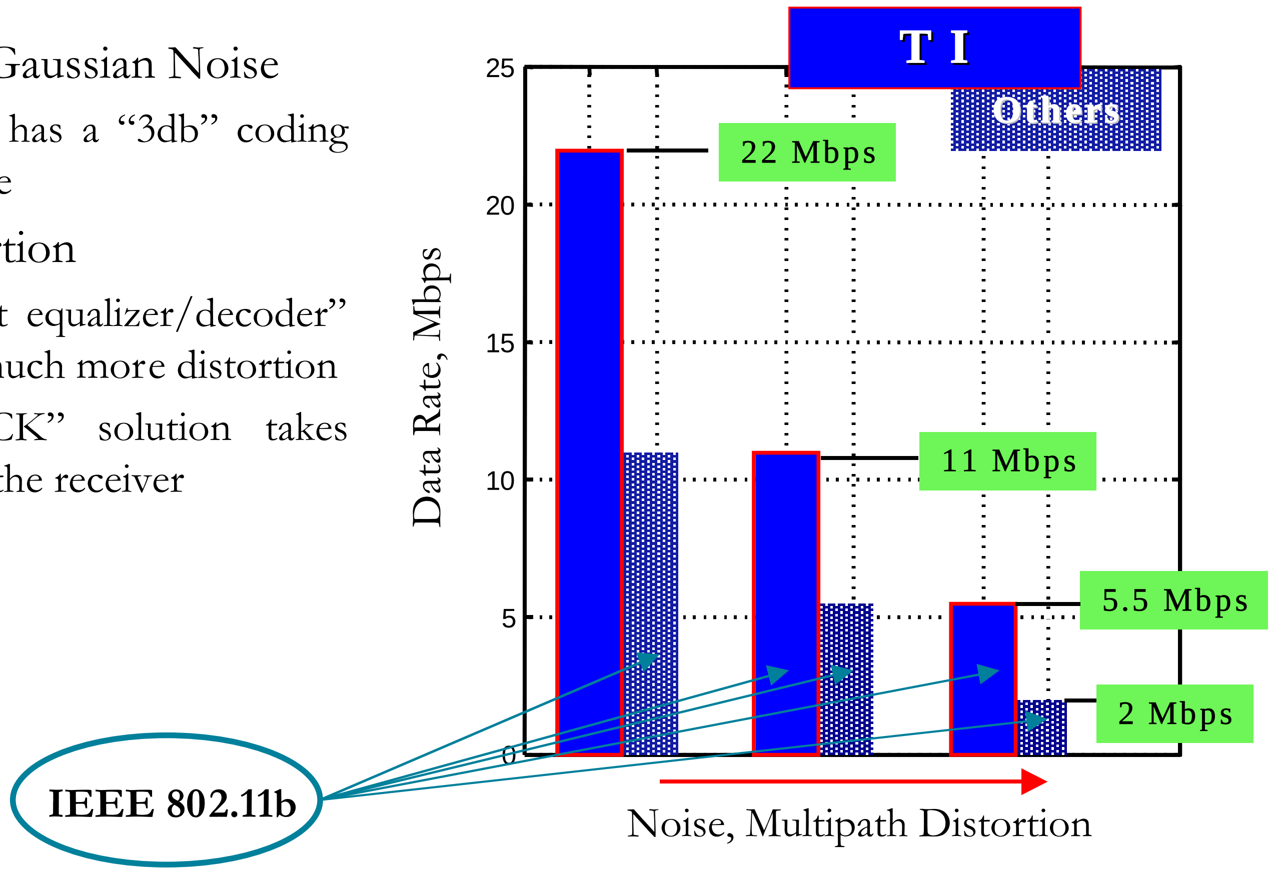
- Introduction
  - Improved utilization of the 2.4 GHz ISM band for wireless Ethernet
- The TI/Alantro 22 Mbps solution
  - How it works
  - Why it is good
- Certification Issues
  - Processing Gain
  - Jamming Requirements
- The ACX101 Baseband Processor
- Status of the IEEE 802.11 Task Group “G”
- Summary

Introduction

"Double the Data Rate" Wireless Ethernet

TI Offers 2x, "Double the Data Rate"

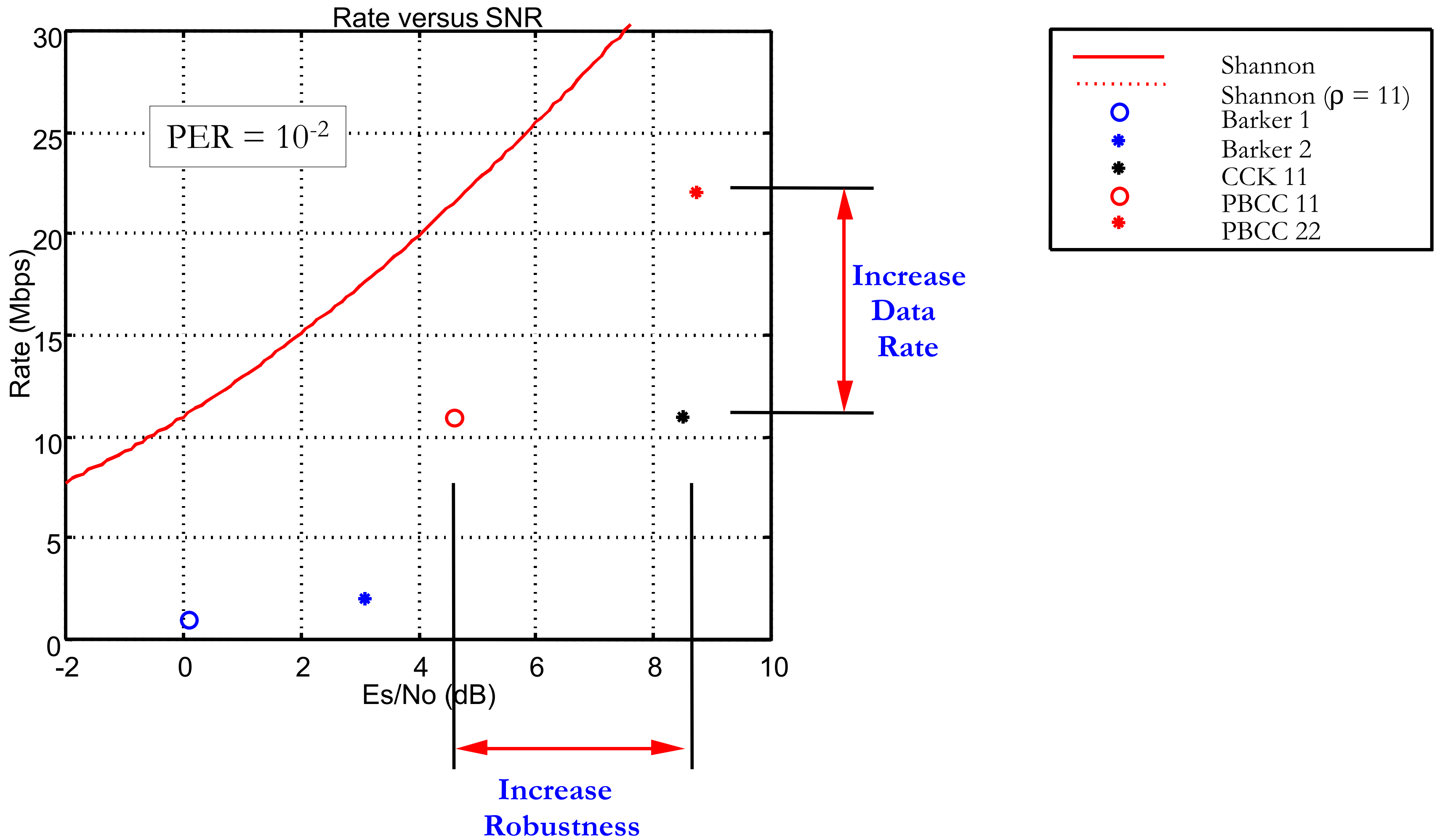
- Additive White Gaussian Noise
  - The TI FEC has a "3db" coding gain advantage
- Multipath Distortion
  - The TI "joint equalizer/decoder" can process much more distortion
  - The TI "CCK" solution takes advantage of the receiver



Why Increase Performance?

- Spectrum is rare and valuable
  - In order to be efficient it demands the most aggressive practical technical solution
  - History: as progress is made, more throughput is achieved
  - Example: Telephone modem technology
    - Fixed 3 kHz channel
    - Initial progress: 300 -> 1,200 -> 2,400 -> 4,800 bits/second
    - Progress was stalled until:
      - Trellis coding, a form of FEC based on convolutional coding, was developed
      - Adaptive signal processing was developed
    - Inspired new wave: 9,600 -> 14,400 -> 28,800 bits/second
- The Alantro/TI technology provides the next wave in wireless Ethernet performance

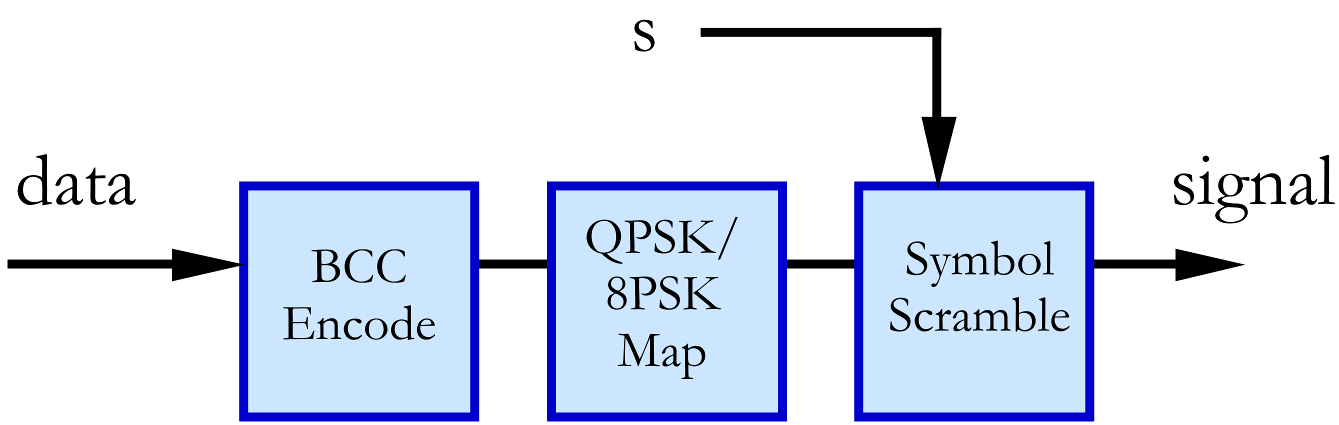
How to Increase Performance?



Packet Binary Convolutional Coding

- Combines Binary Convolutional Coding with Codeword Scrambling
- For 11 (and 5.5) Mbps
  - Rate k=1, n = 2 encoder
  - 64 state
  - QPSK (BPSK) modulation
  - Dfree^2/Es = 9/2 = 6.5 dB
- For 22 Mbps
  - Rate k=2, n=3 encoder
  - 256 state
  - 8PSK modulation
  - Dfree^2/Es = 704/98 = 8.6 dB

PBCC Components



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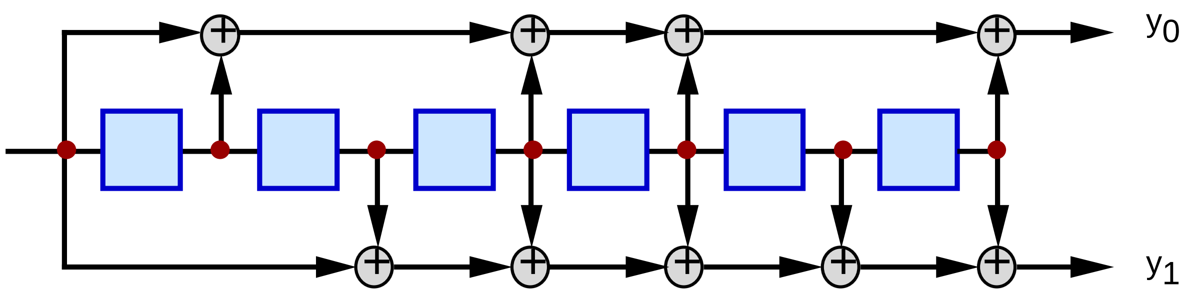
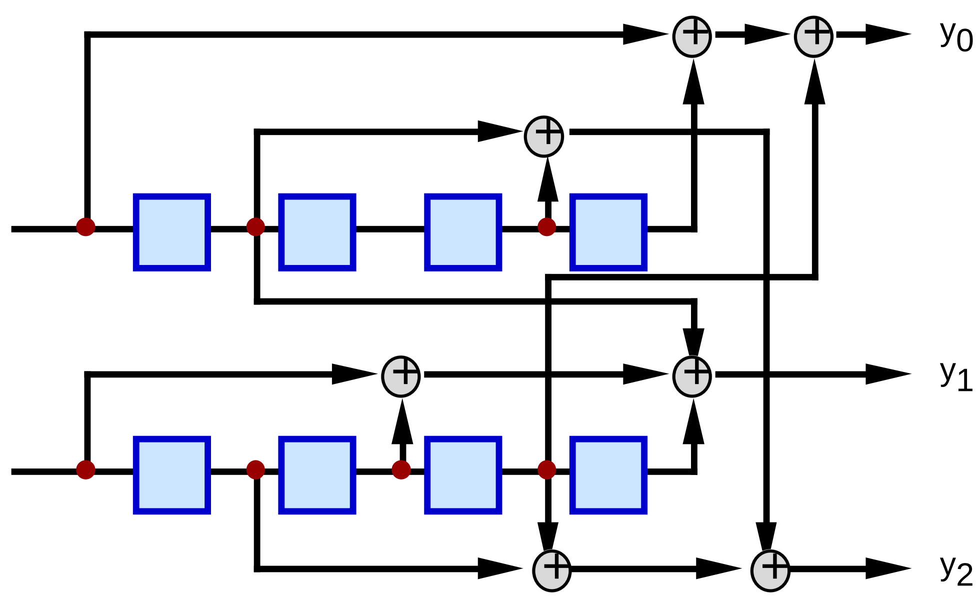
BCC Encoder

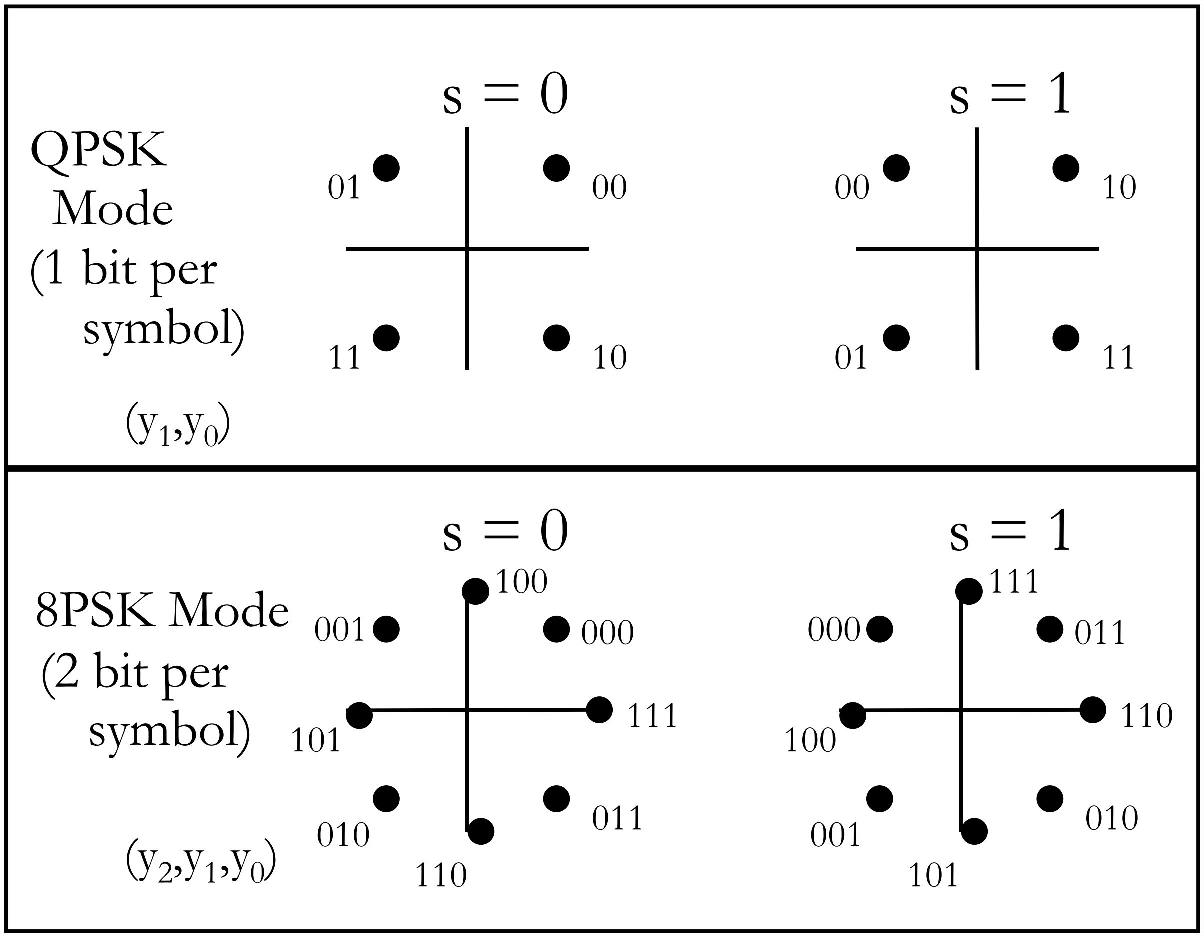
- PBCC-11:



- PBCC-22:



“Symbol Scrambler”



TEXAS INSTRUMENTS

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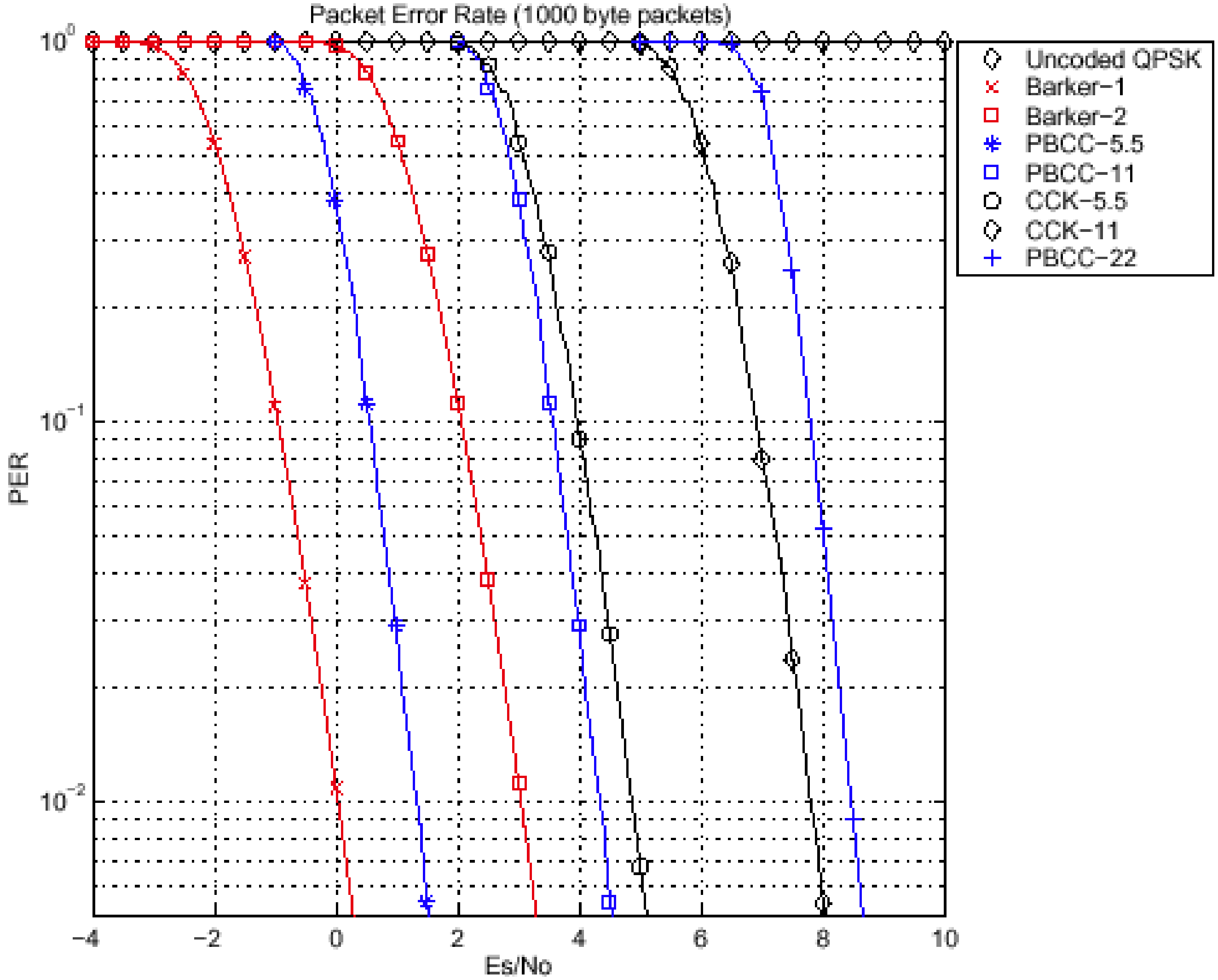
The TI Realization



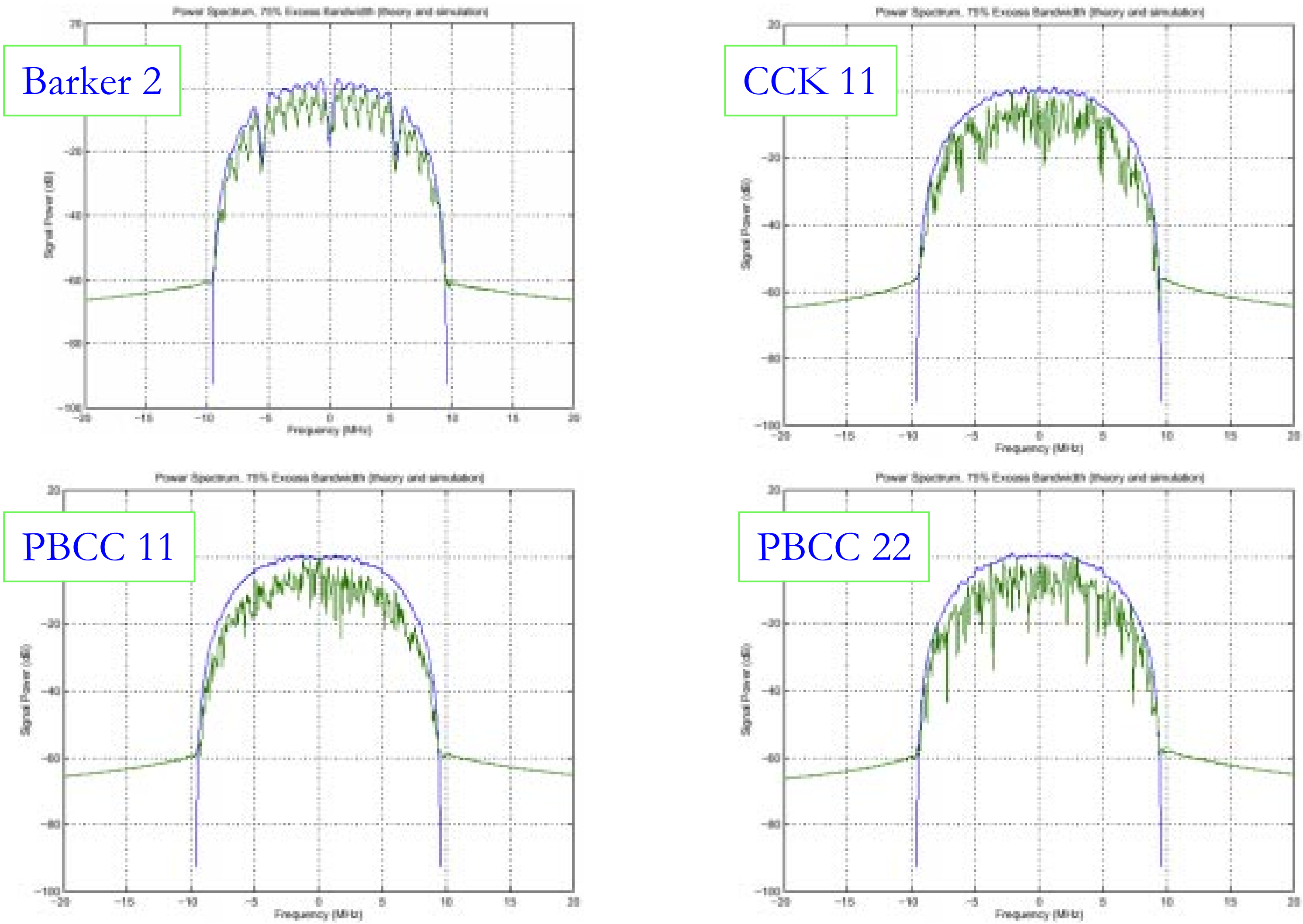
Certification Issues

PBCC-22 should be certified under existing rules

2 Principle Aspects to Certification

- Transmission: **The nature of the transmitted signal**
  - What is the power level?
    - Power Spectrum
- Reception: **Robustness at the receiver**
  - Depends on the character of the transmitted signal and the sophistication of the receiver
  - Processing Gain
    - Measured with respect to a reference
    - Comparison of Shannon Limits
  - Interference Rejection
    - CW Jamming Margin
    - Narrow Band Gaussian
    - Noise

The Transmitted Signal



The Definition of Spread Spectrum

- "I Don't Know How to Define It, But I Know It When I See It"
  - John Cafarella, Proxim
  - This is a self-serving copout
    - There is a long history to the science of digital communications
      - Morse, Nyquist, Shannon, Weiner, Hamming, Elias,…
- Although one does need to make logical definitions, similar difficulties exist with other important communications parameters
  - Signal-to-Noise ratio
  - Bandwidth
  - Power Spectrum, etc.
- Reasonable Definitions Exist (examples to follow)
- Is the definition important? **NO**
  - A means to an end --> robust communications

Massey's Definition

- "Towards an Information Theory of Spread- Spectrum Systems" ,
  - Code Division Multiple Access Communications (Eds. S. G. Glisic and P. A. Leppanen) , 1995, James L. Massey.
- Defined 2 notions of Bandwidth
  - "Fourier" or "Nyquest" Bandwidth
    - Relates to Spectrum Occupancy
  - "Shannon" Bandwidth
    - Relates to Signal Space Dimension
  - Spreading Ratio ρ
    - A system is "spread spectrum" if ρ is large
- This definition is mathematically precise and intuitive
  - This definition argues that high rate (bits/sec/Hz) systems cannot have significant spreading

A Theorem

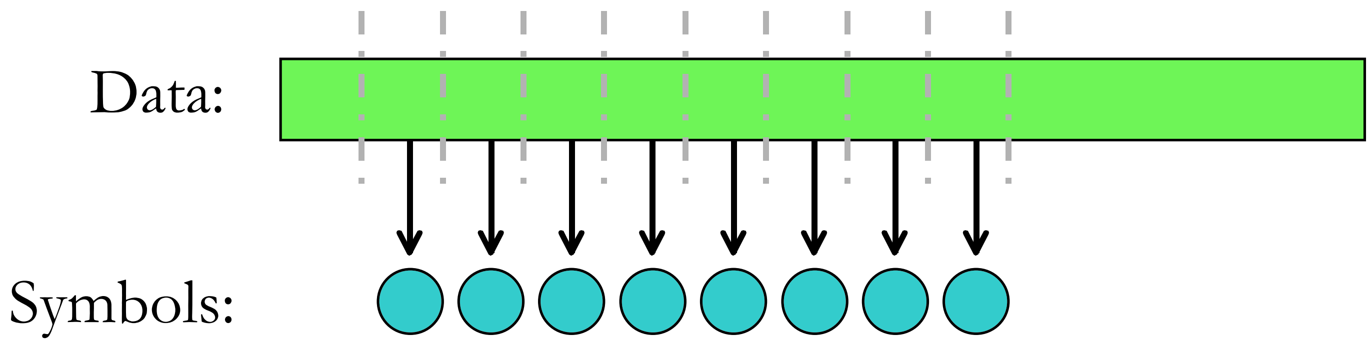
$$\boxed{\rho = \frac{B_{Fourier}}{B_{Shannon}} \geq 1}$$

Massey's Definition Applied to Wireless Ethernet

Scheme	ρ Code Level	ρ Waveform Level
Barker-1	22	40.00
Barker-2	11	20.00
CCK-5.5	1	1.82
CCK-11	1	1.82
PBCC-5.5	2	3.64
PBCC-11	1	1.82
PBCC-22	1	1.82

Other Notions of Signal "Spreading"

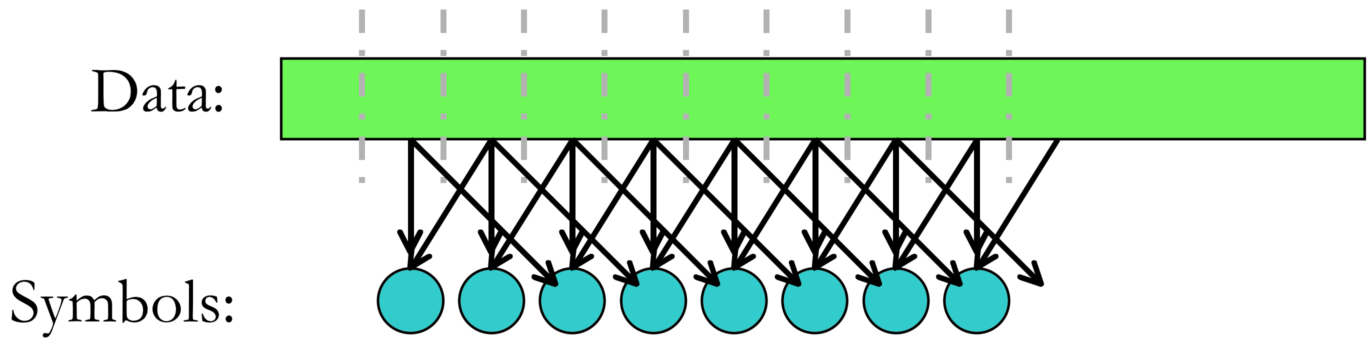
- Uncoded Modulation:
- Break data stream into small pieces
  - map onto independent dimensions



  - Noise occasionally causes symbol error
    ==> data error

In FEC Systems, Information is Spread

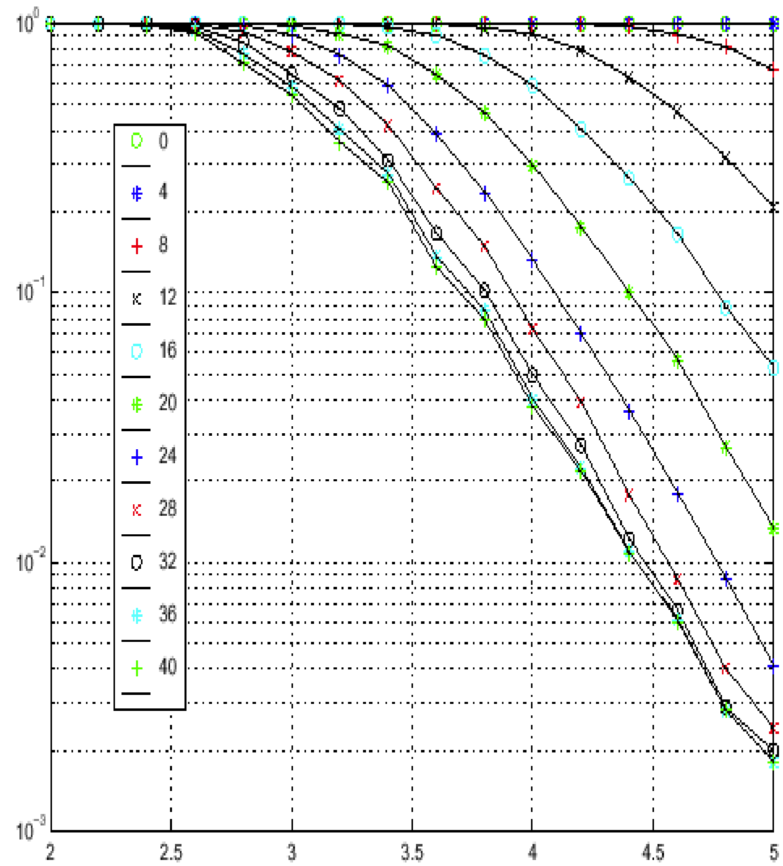
- Coded Modulation:
- Have each bit of data affect many symbols



- Average out the noise with the decoding
- Lesson of Shannon:
  - If you are willing to work (compute) then more throughput is possible

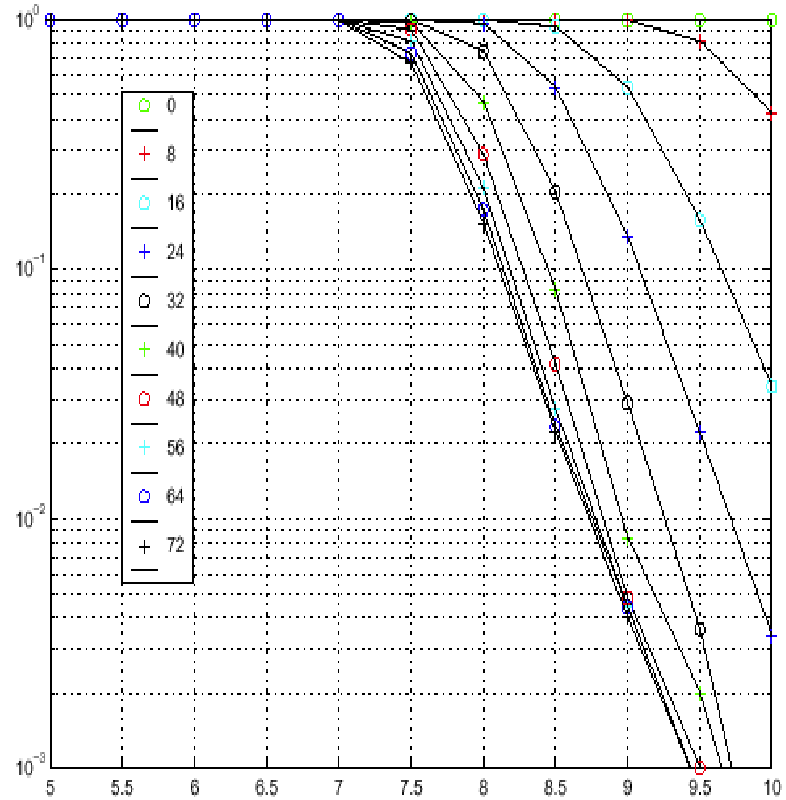
PBCC-11 Pathmemory Requirements

- To perform within 0.5 dB of optimal requires the decoder to observe received symbols in a window that is > 28 QPSK symbols long
  - > 2.5 μsec
    - @ 11Msps



PBCC-22 Pathmemory Requirements

- To perform within 0.5 dB of optimal requires the decoder to observe received symbols in a window that is > 40 8PSK symbols long
  - > 3.6 µsec
    - @ 11Msps



Processing Gain

- *Gain* is respect to a reference, an uncoded signal
  - CCK-11, PBCC-11 --> QPSK
  - PBCC-22 --> 8PSK
- *Processing gain*
  - is defined as the difference between the SNR (Es/ No) required to achieve a threshold BER or PER with the reference scheme and the SNR (Es/ No) required to achieve the same threshold BER or PER when the signal is *processed*.
- *Processing*
  - of the signal includes error control coding and spreading of the signal.
- *Repetition or Rate reduction gain*
  - is the energy gain achieved from the reduction of data rate relative to the reference.

Processing Gain (cont.)

- *Coding gain*
  - is measured on an Eb/ No scale rather than an Es/ No scale. This prevents the apparent increase in performance that has been gained as a tradeoff between Es/ No and rate.
  - it is the **excess gain** from a repetition gain
- *Bandwidth expansion factor gain*
  - With ideal pulse shaping, the TI system which operates at 11 Msps, would occupy 11 MHz of bandwidth. However, the signal is spread to a bandwidth of ~20 MHz. This yields a waveform spreading gain of
    - ~10 log(20/ 11)= 2.6 dB.

P. G. Comparison

Scheme	Rate (Mbps)	Mod	Code	C. G. (dB)	R. G. (dB)	W.G. (dB)	P.G (dB)
Barker-1	1	BPSK	Barker	0.00	13.40	2.60	16.00
Barker-2	2	QPSK	Barker	0.00	10.40	2.60	13.00
CCK-11	11	QPSK	CCK	2.00	3.01	2.60	7.61
PBCC-11	11	QPSK	64 state BCC	5.90	3.01	2.60	11.51
PBCC-22	22	8PSK	256 state BCC	8.10	1.76	2.60	12.46

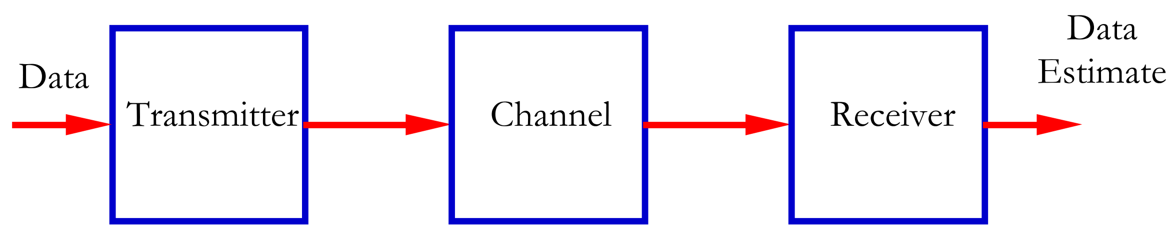
- Processing Gain = Coding Gain + Rate/Spreading Gain
  + Waveform/Spreading Gain

Scheme	Eb/No PER = 10e-2	Coding Gain
Uncoded QPSK	10.5	
Uncoded 8PSK	13.8	
Barker	10.5	0.0
CCK-11	8.5	2.0
PBCC-11	4.6	5.9
PBCC-22	5.7	8.1

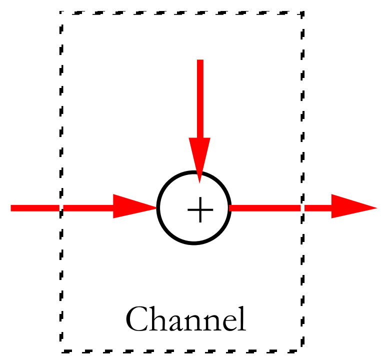
The CW Jamming Margin Test

- The ACX101 will pass the existing test in all modes
  - Including PBCC-22
- This test is useful for eliminating poorly designed systems
  - Shows some degree of robustness
- Other measures of robustness: (e.g., narrow band Gaussian)
  - The PBCC-22 mode is as robust as the CCK-11
  - Any reasonable test that CCK-11 passes will be passed by PBCC-22

The Jamming Margin Test

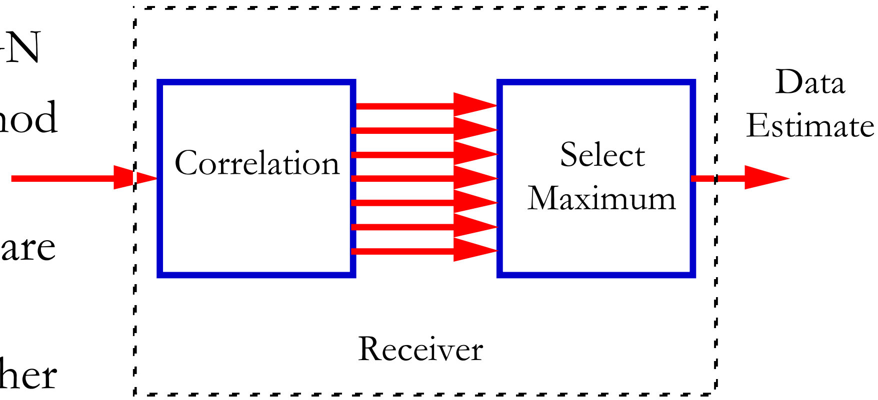


- Spreading and Coding Provides
  - Additive White Gaussian Noise Margin
  - Interference Margin
    - Tonal interference
- A CW signal is added to the transmit signal
- An improvement over uncoded modulation is measured



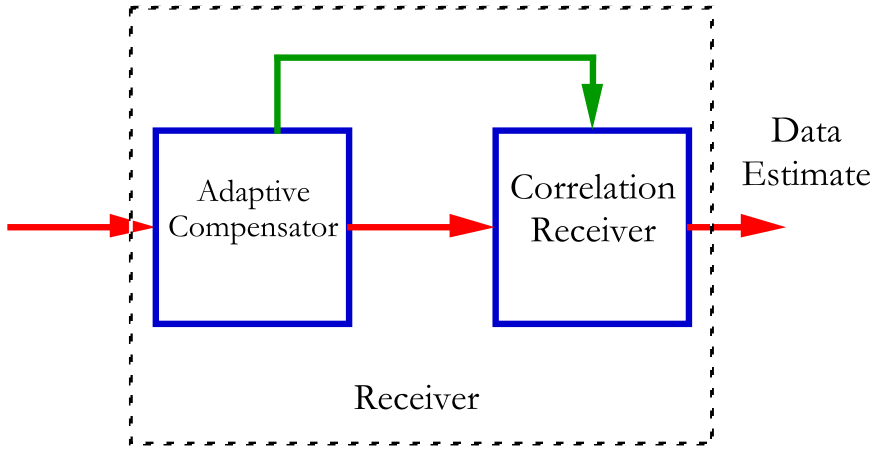
The Problem with the Jamming Margin Test

- A conventional (non-sophisticated) receiver performs a maximum correlation comparison
- This receiver is *maximum likelihood* in AWGN
- The Viterbi algorithm is an efficient method of implementing this receiver
- The AWGN margin and Jamming margin are **proportional** with this receiver
- However, it is susceptible to other impairments
  - Interference
  - Multipath
  - Variable conditions



The Problem (cont)

- Modern receivers implement *adaptive* signal processing algorithms which provide robustness
- The AWGN margin and Jamming margin are **not proportional** with this receiver
- Multipath and interference rejection objectives effectively diminish the CW Jammer
- It is possible to *tweak* the receiver to provide addition CW Jamming margin protection
  – Beyond the requirements of the "real world"



The ACX101 Baseband Processor

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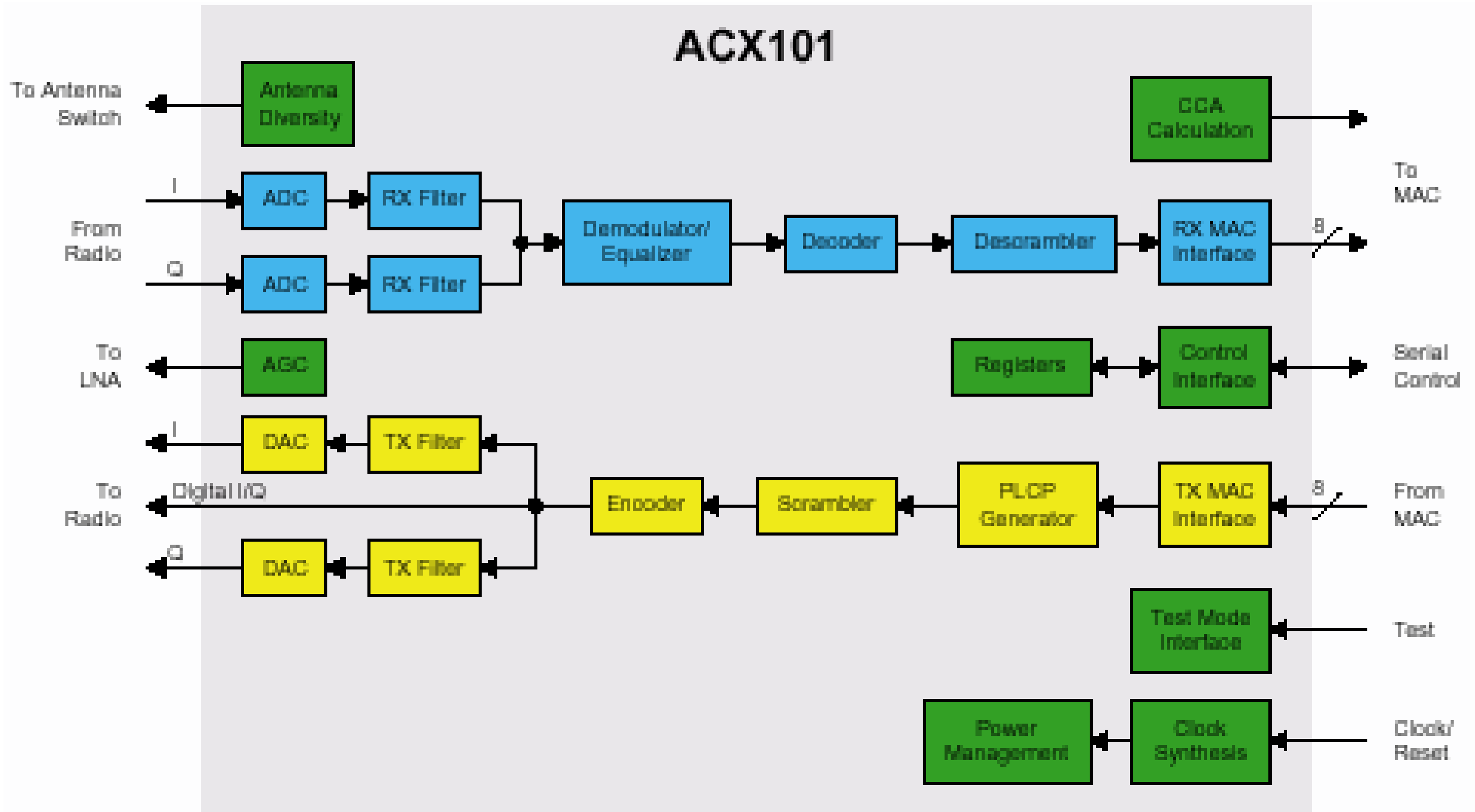

The IEEE 802.11 Task Group G

The Standards Activity

- Official approval was obtain for the PAR (doc. 00/114r2) on Wednesday, September 20, 2000. On Thursday, September 21, 2000, TGg officially meet for the first time. Minutes for the September 18-20, 2000 Session of the HRb SG are available in document 00/287. Minutes for the September 21-22, 2000 Session of TGg are available in document 00/340.
- The group unanimously moved to issue the Final Call for Proposals. All individuals that would like to submit a proposal to TGg must notify the TGg chairperson, Matthew B. Shoemake, by Monday, October 30, 2000 at 11:59PM EST of their intent to present at the November 2000 Plenary in Tampa, Florida, USA.

Proposal Requirements

- General Requirements
  - The proposal must be an extension of the IEEE 802.11b standard.
  - The proposal shall specify a PHY that implements all mandatory portions of the IEEE 802.11b PHY standard
  - Must comply with IEEE 802 patent policy
  - Backward compatibility with 802.11b
  - All proposals must not render existing 802.11b compliant products non-conformant with the resulting, supplemented IEEE 802.11 2.4GHz standard.
  - The proposal shall not repeal any options in the IEEE 802.11b standard.
- MAC Interface Requirements
  - The proposal must be compatible with the IEEE 802.11 MAC standard. Clarification note: Compatibility with the IEEE 802.11 MAC may be achieved by changes to MIB variables.
- Performance Requirements
  - The maximum PHY data rate of the proposal **must be at least 20Mbps**
- RF Requirements
  - All proposals shall operate **in the 2.4GHz band**
  - Channelization same as 802.11b, i.e. same 5MHz channel spacing and center frequencies

Three Surviving Proposals

November 2000 Meeting

- M. Webster, J. Zyren and S. Halford
  - **Intersil**
  - Doc # 388-397
  - Multi-tone OFDM, IEEE802.11a, based
- Tim O'Farrell
  - **Supergold Communications, Ltd.**
  - Doc # 366r1
  - A proprietary single-tone modulation with Reed-Solomon coding
- Chris Heegard, Eric Rossin, Matthew Shoemake, Sean Coffey and Anuj Batra
  - **Texas Instruments, Inc**
  - Doc # 384
  - Single-tone 8 PSK with PBCC

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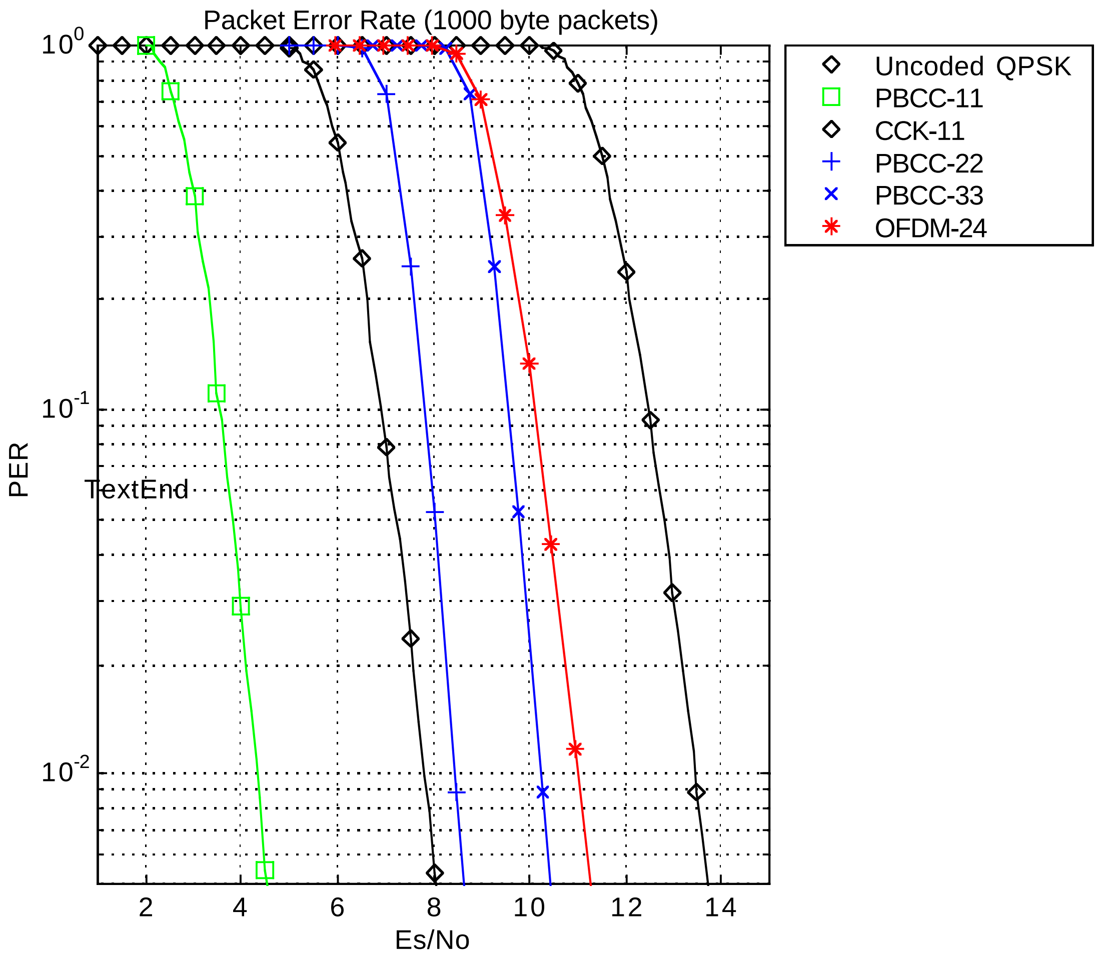
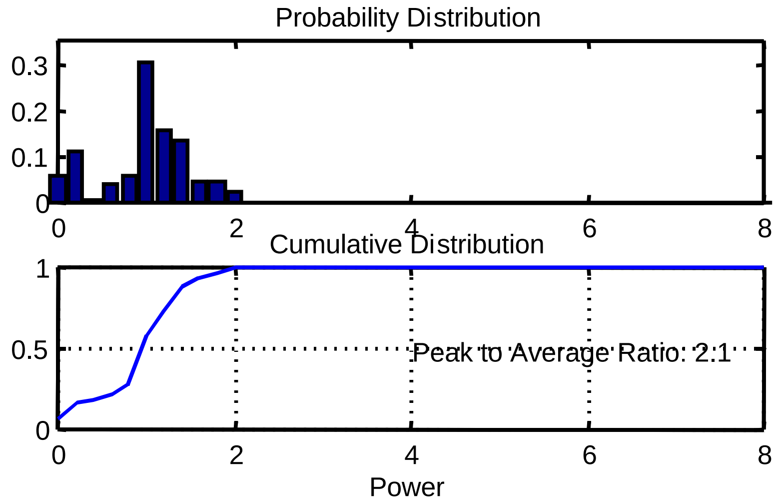
Packet Error Rate for Proposals

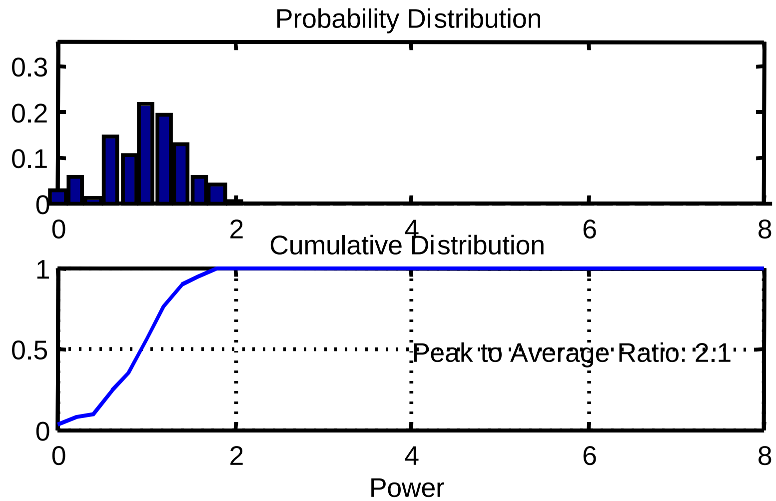


Peak to Average Power

- Barker

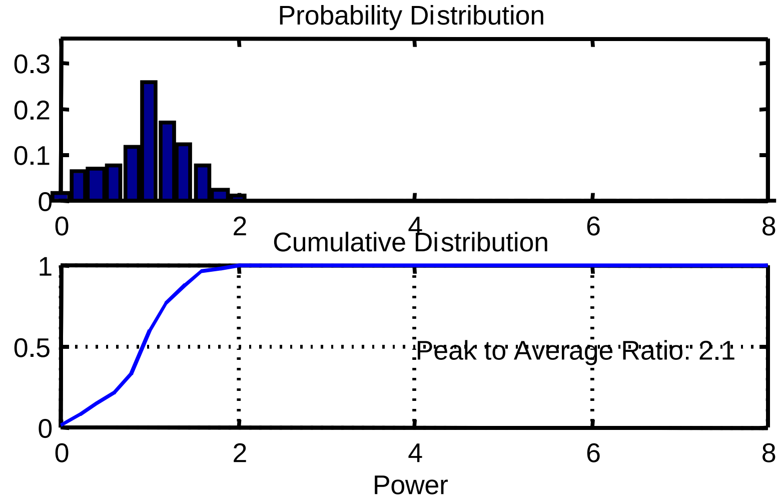


- CCK

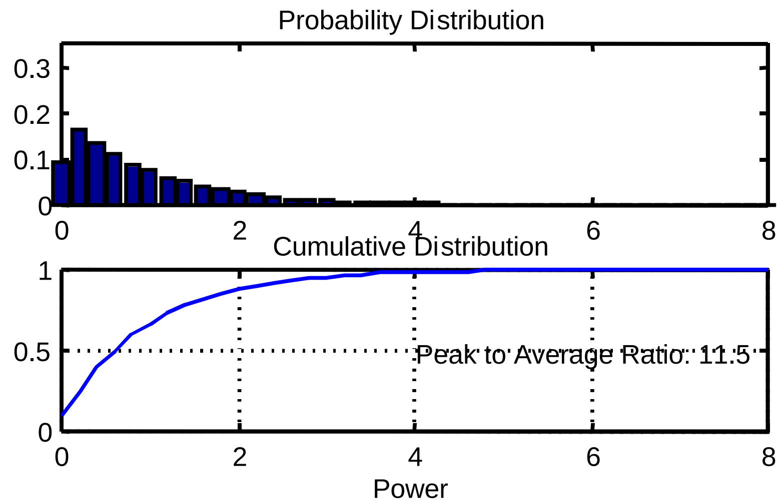


Peak to Average Power (cont)

- PBCC-22



- OFDM-24



Summary

- Alantro/TI has built an extension to the existing IEEE 802.11b standard that is fully backward compatible
- The solution will pass the **existing** FCC rules
  - The spectrum is the same as the existing standard
  - The ACX101, with PBCC-22, is as robust as existing CCK-11 products
    - Will deliver twice the data rate **in the same environment**
  - The 22 Mbps achieves better performance through
    - Sophisticated signal and FEC design
    - Advanced digital communications signal processing algorithms
- The TI solution is the leading contender for the new IEEE 802.11g wireless Ethernet standard
- The OFDM "PAR" problem should be considered as setting interference rules